AFRL-ML-WP-TP-2007-421

PURIFICATION OF CONTAMINATED MIL-PRF-83282 HYDRAULIC FLUID USING THE PALL PURIFIER AND MULTIPLE PROCESS CONFIGURATIONS (PREPRINT)

Carl E. Snyder, Jr., Lois J. Gschwender, Stephen L. Gunderson, and George W. Fultz

NOVEMBER 2006

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE ***(DD-MM-YY)***	**2. REPORT TYPE**	**3. DATES COVERED *(From - To)***
November 2006	Paper Preprint	

4. TITLE AND SUBTITLE	**5a. CONTRACT NUMBER** FA8650-05-D-5050
PURIFICATION OF CONTAMINATED MIL-PRF-83282 HYDRAULIC FLUID USING THE PALL PURIFIER AND MULTIPLE PROCESS CONFIGURATIONS (PREPRINT)	**5b. GRANT NUMBER**
	5c. PROGRAM ELEMENT NUMBER 62102F
6. AUTHOR(S)	**5d. PROJECT NUMBER** 4347
Carl E. Snyder, Jr. and Lois J. Gschwender (AFRL/MLBT) Stephen L. Gunderson and George W. Fultz (University of Dayton Research Institute)	**5e. TASK NUMBER** 60
	5f. WORK UNIT NUMBER 61100002
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
Nonstructural Materials Branch (AFRL/MLBT) Nonmetallic Materials Division Materials and Manufacturing Directorate Air Force Research Laboratory, Air Force Materiel Command Wright-Patterson Air Force Base, OH 45433-7750 University of Dayton Research Institute 300 College Park Dayton, OH 45469	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSORING/MONITORING AGENCY ACRONYM(S)** AFRL-ML-WP
Materials and Manufacturing Directorate Air Force Research Laboratory Air Force Materiel Command Wright-Patterson AFB, OH 45433-7750	**11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)** AFRL-ML-WP-TP-2007-421

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
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14. ABSTRACT
The amount of hydraulic fluid used by all branches of the military is significant both in terms of volume and cost. The disposal of used hydraulic fluid is a cost, time, and logistical component that can be greatly reduced by the purification and reuse of used hydraulic fluid. This report describes a project that evaluated the effectiveness of various hydraulic fluid purification process configurations on the removal of water and particulate contaminants from MIL-PRF-83282 hydraulic fluid in 55-gallon drums.

15. SUBJECT TERMS
Hydraulic fluid, purification, contaminants, MIL-PRF-83282

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT:**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** (Monitor)
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Care E. Snyder, Jr.
Unclassified	Unclassified	Unclassified	SAR	22	**19b. TELEPHONE NUMBER** *(Include Area Code)* N/A

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

Purification of Contaminated MIL-PRF-83282 Hydraulic Fluid

using the Pall Purifier and Multiple Process Configurations

Introduction

The amount of hydraulic fluid used by all branches of the military is significant both in terms of volume and cost. The disposal of used hydraulic fluid is a cost, time, and logistical component that can be greatly reduced by the purification and reuse of used hydraulic fluid. This report describes a project that evaluated the effectiveness of various hydraulic fluid purification process configurations on the removal of water and particulate contaminants from MIL-PRF-83282 hydraulic fluid in 55-gallon drums.

Materials and Methods

The fluid used in this evaluation was fresh MIL-PRF-83282 hydraulic fluid that was contained in a 55-gallon drum. The actual fluid amount contained in the drum and subjected to the purification process was approximately 53 gallons. The purifier used in the tests was a Pall portable purification unit model #PE-00440-1Z (Figure 1) and all testing was carried out under ambient conditions (above 60°F/15°C). A slurry of natural Arizona road dust containing particles of various sizes was introduced into clean MIL-PRF-83282 and used to simulate particulate contamination. Laboratory-supplied distilled water was used for the water contaminant.

Sampling of the fluid was accomplished by inserting one end of a ½" outside diameter glass tube into the drum and the other end fixed to a clean collection flask then drawing up approximately 6 oz. of the fluid into the flask by applying a slight vacuum (Figure 2). The fluid in the flask was then transferred to a clean sample bottle for analyses. The glass tubing and collection flasks were thoroughly washed with filtered hexane between sampling sets then the tube purged with N_2 and the flasks heated in an air-circulating oven at 200°C for 1 hour. During a second run using the two-drum purification process configuration, a new sampling technique was introduced that allowed the fluid to be drawn directly into the sample bottle so there would be no need to use a collection flask (Figure 3). This eliminated the fluid transfer step from the flask to the bottle and also the need to wash the sampling flasks after each sample was taken. The new technique utilized a vacuum connector between the end of the sampling tube and the sample bottle. Applying a slight vacuum to the connector allowed the fluid to be drawn up the tube, through the connector and into the sample bottle. However, due to the increased length on the receiving end of the glass sampling tube caused by the vacuum connector, the inlet/suction end of the glass tube was not long enough to reach the bottom fluid sample so the original vacuum flask sampling technique was used for the bottom fluid section sample. The glass tube was still washed as previous with the vacuum connector being washed in the same manner as the tube.

Samples were analyzed using a HIAC Royco model 8000A automatic particle counter and Karl-Fisher model 447 Coulomatic Titrimeter to determine the amount of particle and water contamination, respectively. Gravimetric analysis was performed in place of or in addition to using the automatic particle counter for several of the sample sets.

Procedure

This project evaluated two different purification process configurations. The first configuration utilized a “two-drum” set-up where the contaminated fluid was passed from its original drum, through the purifier then into a clean empty drum (Figure 4). This was followed by cycling the fluid between the purifier and the second or “clean” drum only (Figure 5). The second configuration utilized a “single-drum” setup where the contaminated fluid was cycled only between the purifier and the original fluid drum. Various lengths of discharge tubing (12, 18 and 24 inches) were evaluated within the single-drum purification method to determine if this had any effect on the results of the purification process.

Before starting the very first test, the new, clean fluid was sampled from the top (~2” below fluid surface), middle and bottom (~2” from drum bottom) and analyzed for particulate and water content as a baseline and to determine how much of each contaminant had to be added prior to starting the experiment. Water content was <100 ppm, the particulate level was NAS 1638 Class 6 and the gravimetric analysis was <1.0 mg/mL. While the specification limit for particulates in new MIL-PRF-83282 hydraulic fluid is NAS 1638 Class 5, this is not expected for fluid stored in drums because drums are allowed to “breathe”. Then, while stirring the clean hydraulic fluid using an air-driven mixer, the particulate slurry was added until a sample drawn from the middle of the fluid registered a particle reading of NAS 1638 Class 12 or a gravimetric reading >1.0 mg/mL. Then, distilled water was added until the middle sample registered 600-700 ppm of water. During the test run, samples were taken from the top, middle and bottom of the fluid at predetermined time intervals until the minimum cleanliness limits for MIL-PRF-83282 was reached (NAS 1638 Class 5 for particulates and/or <1.0 mg/mL and <100 ppm water).

Two-Drum Purification Process Configuration

Following the contamination of the clean hydraulic fluid used in the two-drum configuration, the mixer was stopped and removed and the fluid was allowed to settle for 72 hours prior to starting the purification process. Samples were taken at 24 hour intervals from the top, middle and bottom of the fluid in an attempt to document the kinetics of the settling process.

After the 72-hour settling time, a 32”-long 6061 T-6 steel inlet/suction tube was connected to a quick-disconnect assembly in the large bung-hole of the contaminated fluid drum lid. The bottom of the tube was situated approximately 2” from the bottom of the drum. The lid was then secured onto the drum. Next, the inlet/suction hose of the Pall purifier was attached to the other end of the quick-disconnect assembly of the contaminated fluid drum. The outlet/discharge hose from the Pall purifier was attached to a quick-disconnect assembly in the small bung-hole of a clean empty drum lid. A 12”-long 6061 T-6 steel tube having an inside diameter of approximately 3/4” was attached to the opposite end of the quick-disconnect assembly to discharge the fluid into the clean empty drum.

Prior to starting the purification process, venting of each of the drums to prevent vacuum and pressure buildup was accomplished by loosening the cap in the bunghole not in use on each drum lid. Then the purifier was started and the fluid was drawn from the contaminated fluid drum, through the purifier and into the second drum in just under 20 minutes. Following the single pass purification, samples were taken from the top, middle and bottom of the fluid in the second drum and evaluated for particles and water content. The inlet/suction tube from the original contaminated fluid drum was cleaned and then attached to the large bunghole in the lid of the second drum. Cycling of the fluid between the second drum and the purifier was begun with samples taken from the top, middle and bottom of the fluid every 15 minutes for the first hour and then every hour after that until the minimum requirements for cleanliness were reached (NAS 1638 Class 5 for particulates and/or <1.0 mg/mL and <100 ppm water).

Single-Drum Purification Process Configuration

After the two-drum purification process was completed, six gallons of additional new, clean MIL-PRF-83282 hydraulic fluid was added to the second drum. This was done to make up for the fluid that was not transferred from the original contaminated drum to the second drum and also to make up for fluid lost due to sampling. The inlet/suction and outlet/discharge tubes that were used in the two-drum method were left in place for the single-drum method. A sample from the middle of the fluid was taken and evaluated for particles and water content to confirm the cleanliness of the fluid. The fluid in the drum was then contaminated as previous and cycling of the fluid between the drum and purifier was started immediately (i.e., no waiting/settling period). During the run, samples were taken from the top, middle and bottom of the fluid every 15 minutes for the first hour and then every hour after that until the minimum cleanliness limits were reached (NAS 1638 Class 5 for particulates and <100 ppm water).

This procedure for the single-drum method was repeated using the 18" and 24" discharge/outlet tubes. Also, the fluid in the drum was topped off before each run with approximately 1 gallon of new, clean MIL-PRF-83282 hydraulic fluid to make up for the fluid lost due to sampling.

Results and Discussion

The results from all of the runs are shown in Tables 1-7. At the beginning of each test run, all of the fluids had a NAS 1638 particle count reading of 12 and water content between 600-700 ppm. Generally, the fluid reached the minimum cleanliness limits within a 2-hour time period. Transferring the fluid from one drum, through the purifier and to another drum seemed to have the greatest effect on contaminant removal. Specifics of each of the test runs are discussed below.

Two-Drum Purification Process Configuration

Run #1

The results from the first run using the two-drum purification process configuration are shown in Tables 1 and 2. Prior to adding any contaminants to the new, clean fluid, samples were taken from the top, middle and bottom of the fluid and evaluated for particle count, particle weight and water content. The samples registered a NAS 1638

Class 6 reading for particle count, 0.37 mg/mL for particle weight (top and middle samples) and a range of 91-99 ppm water, all typical for drums of new MIL-PRF-83282 hydraulic fluid.

Since high water content can interfere with the automatic particle count determinations, the Arizona road dust slurry was added first until a sample taken from the middle of the fluid produced a reading of NAS 1638 Class 12. Then distilled water was added incrementally until the water content for the middle fluid sample was at least 600 ppm. A reading of 613 ppm of water was achieved following the addition of 105 mL of distilled water. Then three more samples were taken from the top, middle and bottom of the fluid and analyzed for water with the top and bottom samples also being analyzed for weight of particulate contamination. These samples were designated as initial samples (time = 0). While the particulate weight of the top and bottom samples measured 1.70 and 1.59 mg/mL, respectively, the water readings dropped by up to 10% from the previous reading ranging from 543-596 ppm (569 ppm avg.). This may have been caused by the tendency of water to adhere to the sides of the barrel under saturated conditions. The fluid was then allowed to set for three days with samples taken after each 24-hour period.

After 24 hours, top, middle and bottom fluid samples were taken and analyzed for particle count and water content. All three samples had particle counts of NAS 1638 Class 12, however, the actual particle counts were generally reduced within each size category, especially the 25µm and larger sized particles. The particle counts of the largest sized group, measuring >100µm, decreased by 90% (Table 2). The water contents ranged from 574-608 ppm (594 ppm avg.).

Top, middle and bottom samples were again taken from the fluid after 48 hours and analyzed for particle count and water content. At this point, the particles from the top section of the fluid had settled out enough so that a NAS 1638 Class 11 reading was obtained. The middle and bottom sections remained at NAS 1638 Class 12 though the actual particle counts within each of the particle sized groups continued to decrease. Water content was maintained with readings for the three sections ranging from 576-597 ppm (588 ppm avg.).

After 72 hours, both the top and middle fluid sections of the fluid registered NAS 1638 Class 11 for particle count while the bottom fluid sample remained at NAS 1638 Class 12. Actual particle counts continued to decrease but only significantly for those in the 15-25µm and 25-50µm-sized ranges. Particle weights were measured for the top and bottom samples resulting in 0.864 and 0.836 mg/mL, respectively, a 50% drop from the 0 hour measurement and below the gravimetric cleanliness requirement in the MIL-PRF-83282 specification. Water content again held steady ranging from 589-597 ppm (593 ppm avg.).

After the transfer of the fluid from the original contaminated drum, through the purifier and into the second clean drum, both the water and particulates had been reduced by approximately 50%. Particle counts for the top, middle and bottom samples measured NAS 1638 Class 6, 5 and 6, respectively; while the water content ranged from 288-294 ppm (291 ppm avg.).

Particle count NAS 1638 Class readings for each of the three fluid sections remained in the 5-6 range for the next 45 minutes of cycling the fluid between the second drum and

the purifier. After 1 hour of purification, all three fluid sections were NAS 1638 Class 5 which met the MIL-PRF-83282 cleanliness requirement. The water content continued to decrease during this time but required between 1-2 hours to reach the minimum requirement of <100 ppm.

Particle count NAS 1638 Class, contaminant weight, and water content of the residual fluid in the original contaminated fluid drum measured 12, 1.38 mg/mL and 520 ppm, respectively. The actual particle count readings for the larger particle size groups (>25µm) were high relative to the original starting amounts indicating that settling did occur with the larger particles concentrated at the very bottom of the fluid.

Run #2

The second run using the two-drum purification process configuration was carried out similarly to the first run with the results shown in Tables 3 and 4. The particulate slurry and distilled water were added to the clean fluid to give readings for the middle section sample of NAS 1638 Class 12 and 628 ppm for particle count and water content, respectively. The actual quantity of particles measured within each of the particle-sized groups for this run, however, was significantly greater than the first run.

The particle count NAS 1638 Class and water content results for the samples taken from the top, middle and bottom sections to represent time = 0 were 12 and ranged from 625-630 ppm, respectively. Over the next three days, the particle count NAS 1638 Class remained 12 but the water content dropped approximately 10% to a range of 564-585 ppm (576 ppm avg.) for the 72-hour samples. Also, similar to the first run, the actual particle counts within the larger-sized particle groups (>25µm) decreased significantly indicating that settling of these particles was occurring (Table 4). Beginning with the 24-hour samples, the modified sampling technique was introduced. This technique utilized a vacuum connector between the end of the sampling tube and the sample bottle. Applying a slight vacuum to the connector allowed the fluid to be drawn up the tube, through the connector and into the sample bottle (Figure 3).

Following the transfer of the fluid from the original contaminated drum, through the purifier and into the second clean drum, both the water and particulates had been reduced by approximately 50%. Particle count NAS 1638 Classes for the top, middle and bottom samples measured 6, 7 and 6, respectively; while the water content ranged from 300-308 ppm (304 ppm avg.).

During the course of cycling the fluid between the second drum and purifier, the water content dropped in a similar fashion as the first run requiring 2 hours for the top, middle and bottom samples to reach the minimum requirement of <100 ppm. Particle count NAS 1638 Class readings for the top, middle and bottom samples over this time remained at 6 and 7. After 3 hours of cycling, the particle count NAS 1638 Class readings were 5, 4 and 6 for the top, middle and bottom samples, respectively. The original sampling method was used to obtain all three section fluid samples after 4 hours of cycling where the NAS 1638 particle count Classes for the samples met the cleanliness requirement with the results being 5, 4 and 5, respectively. Charts showing the particulate and water removal results for each of the two-drum process configuration runs are shown in figures 6 and 7, respectively.

Single-Drum Purification Process Configuration

12" Discharge Tube

Results using the single-drum purification process configuration and the 12" discharge tube are shown in Table 5. The fluid was contaminated as previous using the particulate slurry and distilled water to give contamination levels of NAS 1638 Class 12 particulate and 665 ppm water. After 2 hours of cycling the fluid through the purifier, the particulate content had been reduced to the minimum cleanliness requirement of NAS 1638 Class 5. After 3 hours, the water content had been reduced to the minimum cleanliness requirement of <100 ppm with the range of values for the three fluid section samples (top, middle and bottom) being 64-78 ppm (73 ppm avg.).

18" Discharge Tube

Results using the single-drum purification process configuration and the 18" discharge tube are shown in Table 6. The beginning fluid contamination levels were NAS 1638 Class 12 particulate and 700 ppm water. Two hours of cycling the fluid through the purifier were required to reduce the particulate contamination to the minimum cleanliness requirement of NAS 1638 Class 5 (the middle and bottom samples each measured Class 4). Also after this same time period (2 hours), the water content had been reduced to just under the minimum cleanliness requirement of <100 ppm with the range of values for the three fluid section samples being 94-97 ppm (96 ppm avg.).

24" Discharge Tube

Results using the single-drum purification process configuration and the 24" discharge tube are shown in Table 7. The beginning fluid contamination levels were NAS 1638 Class 12 particulate and 672 ppm water. Similar to the 18" discharge tube test, 2 hours of cycling the fluid through the purifier reduced the particulate contamination to the minimum cleanliness limit of NAS 1638 Class 5 (the top and middle samples each measured Class 4). The water content was reduced to under the minimum cleanliness requirement of <100 ppm after 2 hours as well with the range of values for the three fluid section samples being 78-89 ppm (84 ppm avg.).

Discharge Tube Comparison

Plots showing a comparison of the particulate and water removal using each of the three discharge tubes are shown in figures 8 and 9, respectively. All three runs reached the minimum level of cleanliness limits (NAS 1638 Class 5 for particulates and <100 ppm water) in 2-3 hours. It may be said that the longer the tube, the better the system operates to remove particulates, but this is not significant or clear-cut based on the results. The plot showing water removal does display a minor advantage to using the longer discharge tube; however, the advantage does not appear to be significant.

Conclusions

This project evaluated the effectiveness of various hydraulic fluid purification process configurations on the removal of water and particulate contaminants from MIL-PRF-83282 hydraulic fluid in 55 gallon drums. The two primary configurations included a two-drum system; which involved a single pass through the purifier from one drum to another followed by cycling the fluid between the purifier and second drum; and a single-drum system which involved cycling the fluid between the purifier and the single drum

only. The former method included a three-day settling period prior to starting the purification process while the latter configuration evaluated the effects of three different discharge tube lengths on the contamination removal process.

After three days of allowing the contaminated hydraulic fluid to set under ambient conditions, it still registered high levels of particulates (NAS 1638 Class 12) and water (593 ppm). But the actual amounts of particulates within each size category did show a significant decrease over this time, especially for the larger-sized particles, indicating that they were settling out of the fluid (Tables 2 and 4). There was no significant change in the water content or its distribution throughout the fluid.

Following the single pass of the fluid from one drum through the purifier then into a second drum, used in the two-drum method, the level of contamination was reduced by about 50%. The cleanliness requirements, in terms of water and particulates, for MIL-PRF-83282 hydraulic fluid were achieved after 2 hours of cycling the fluid between the drum and the purifier for both the two-drum and single-drum configurations. This would indicate that the single-drum method would suffice to clean the fluid and does not require a second drum or a changing out of the purification unit hoses.

With regard to the variable lengths of discharge tubing, it is not clear as to its effect on the contamination removal process based on the tests run here and the associated results. It does appear that the primary advantage to using a longer discharge tube may be to reduce the level of water contamination more quickly.

While the hydraulic fluid cleaning in drums was successful, that was because we were removing volatile or insoluble (particulate) contaminants. Higher boiling, soluble contaminants like JP-8, engine oil, greases, etc are not capable of being removed via purification so if cleaning of used hydraulic fluid in drums is going to be done, the hydraulic fluid in the drums has to be free of those types of contaminants. Very scrupulous segregation of used oils, greases, fuel must be accomplished to safely purify used hydraulic fluid collected in drums.

Acknowledgements

The authors would like to gratefully acknowledge Captain John M. Yerger and the AMC Battlelab for funding this research and Charles Tobin, Timothy Jenney and Timothy Reid of the University of Dayton Research Institute for their assistance in setting up and running the test rig and performing sample tests.

Figure 1: Pall portable purification unit

Figure 2: Fluid sampling from drum using the vacuum flask method

Figure 3: Fluid sampling from drum using the vacuum connector method

Figure 4: Two-drum (drum-to-drum) purification set-up

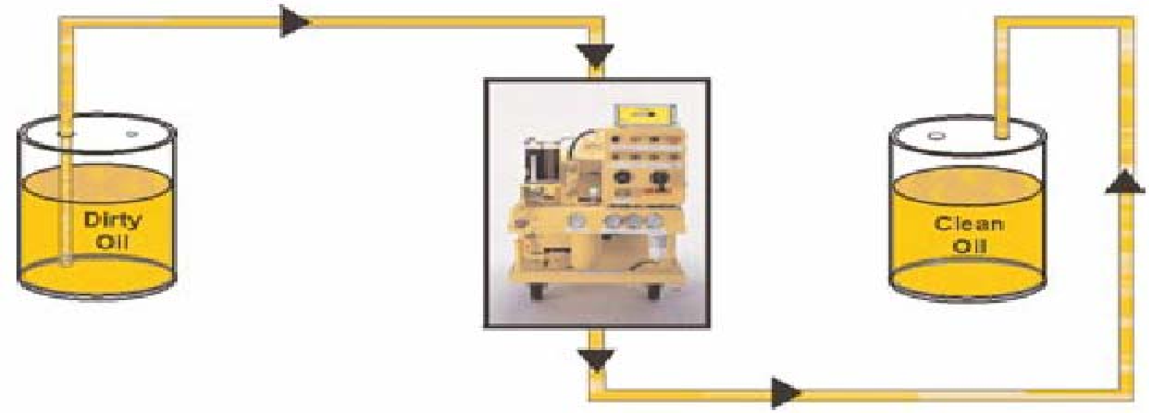

Figure 5: Single-drum purification set-up

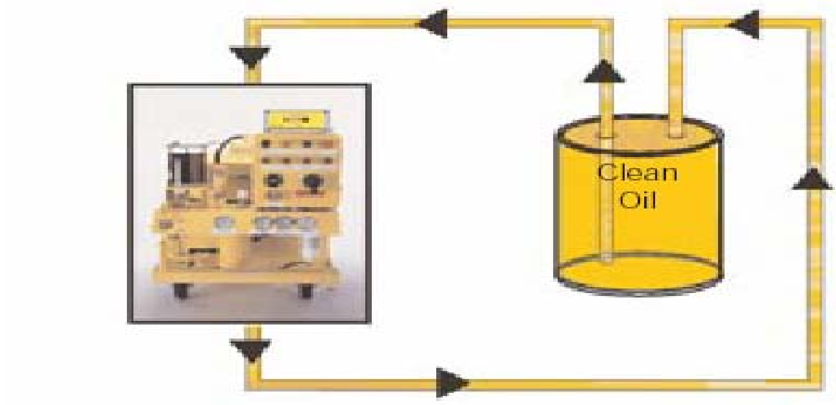

Figure 6: Particulate removal results of the two-drum purification process configuration runs (the drop from NAS 1638 Class 12 to 6 at 0 hours is following the single pass through the purifier)

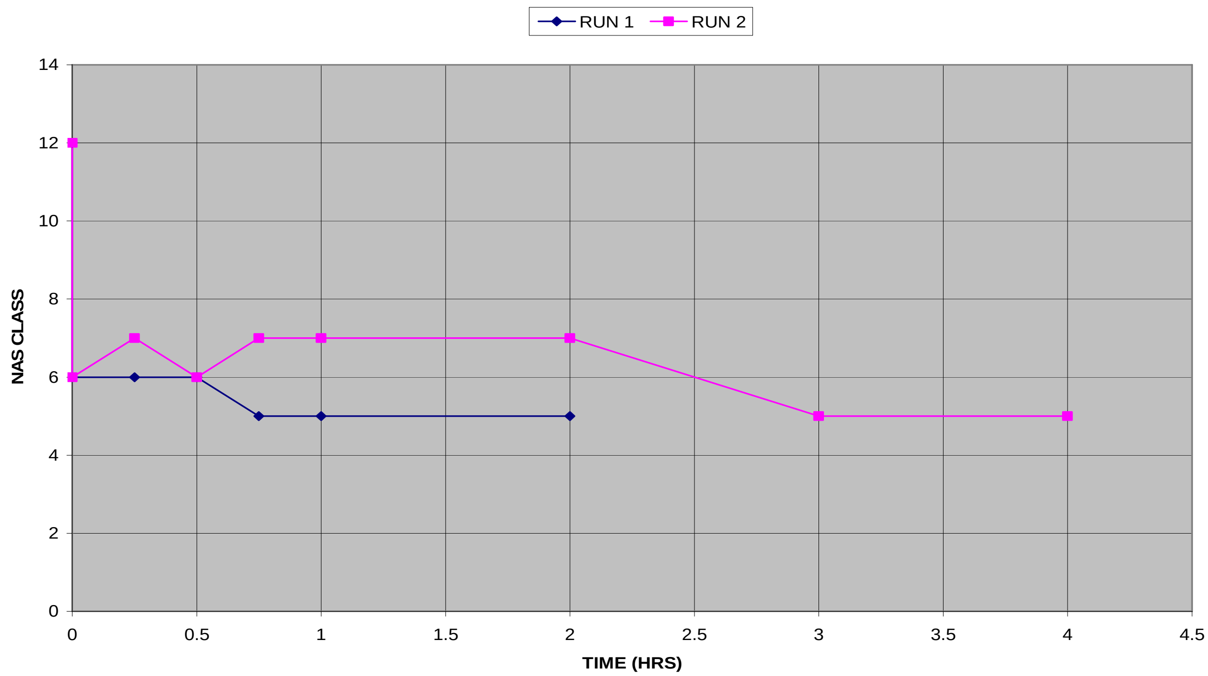

Figure 7: Water removal results of the two-drum purification process configuration runs (the drop in water content at 0 hours is following the single pass through the purifier)

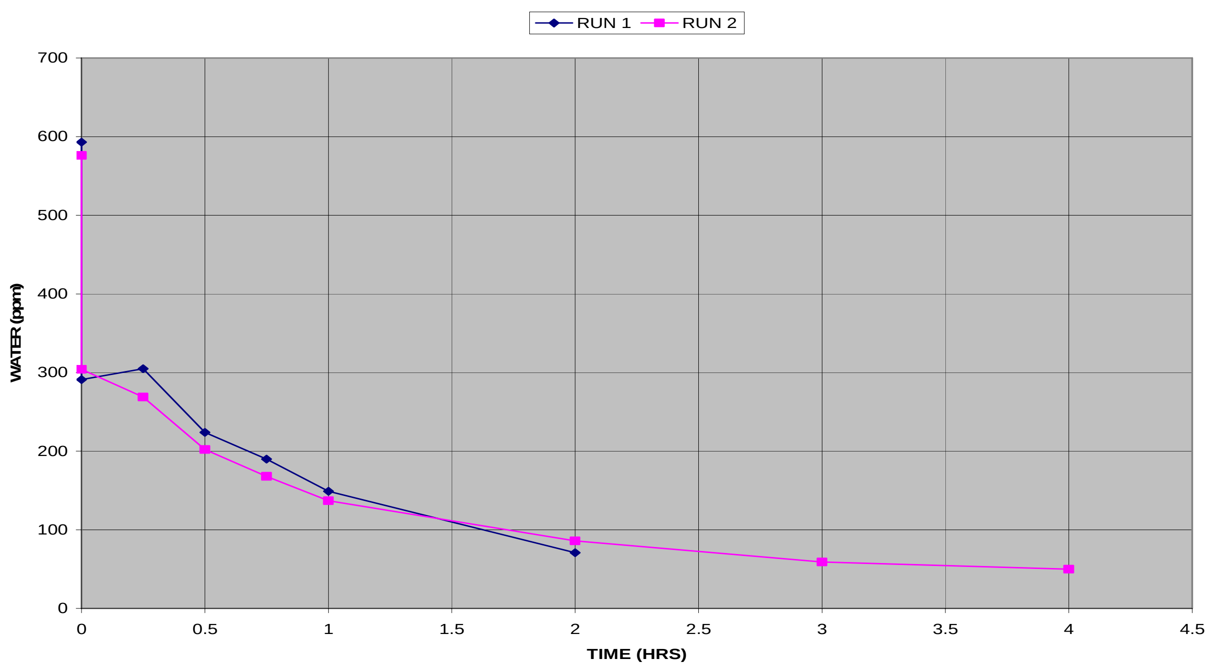

Figure 8: Comparison of particulate removal between three different lengths of discharge tubing using the single-drum purification process configuration

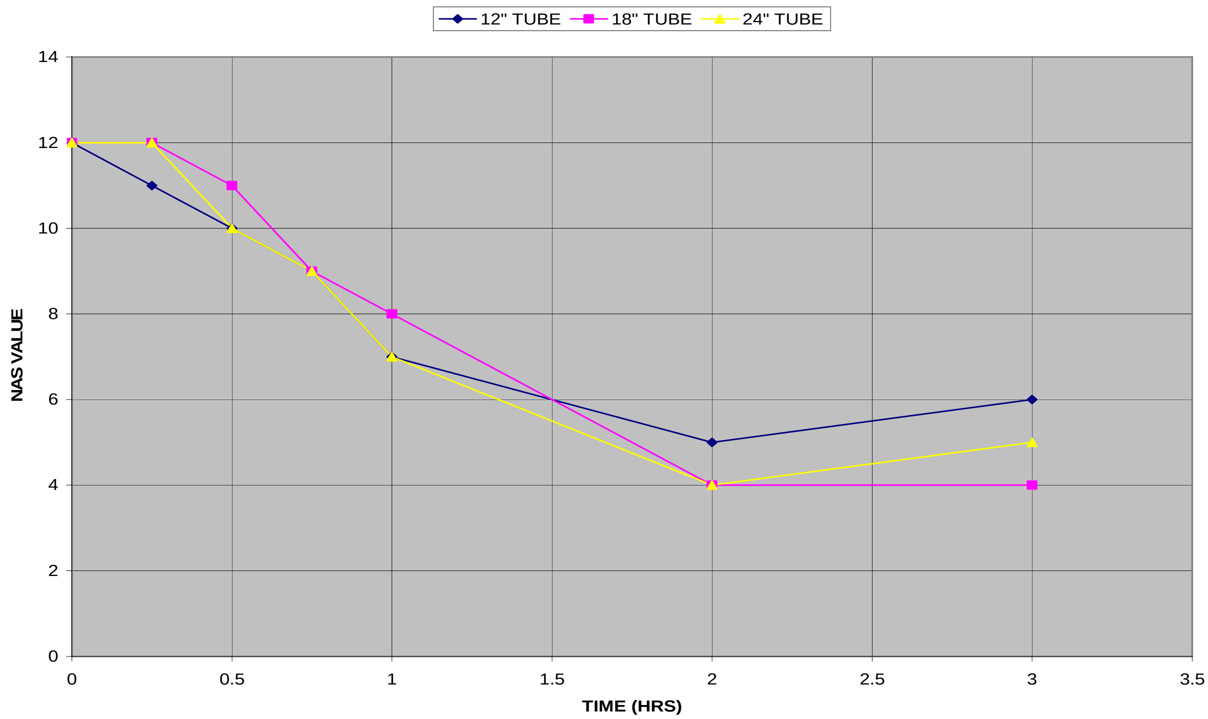

Figure 9: Comparison of water removal between three different lengths of discharge tubing using the single-drum purification process configuration

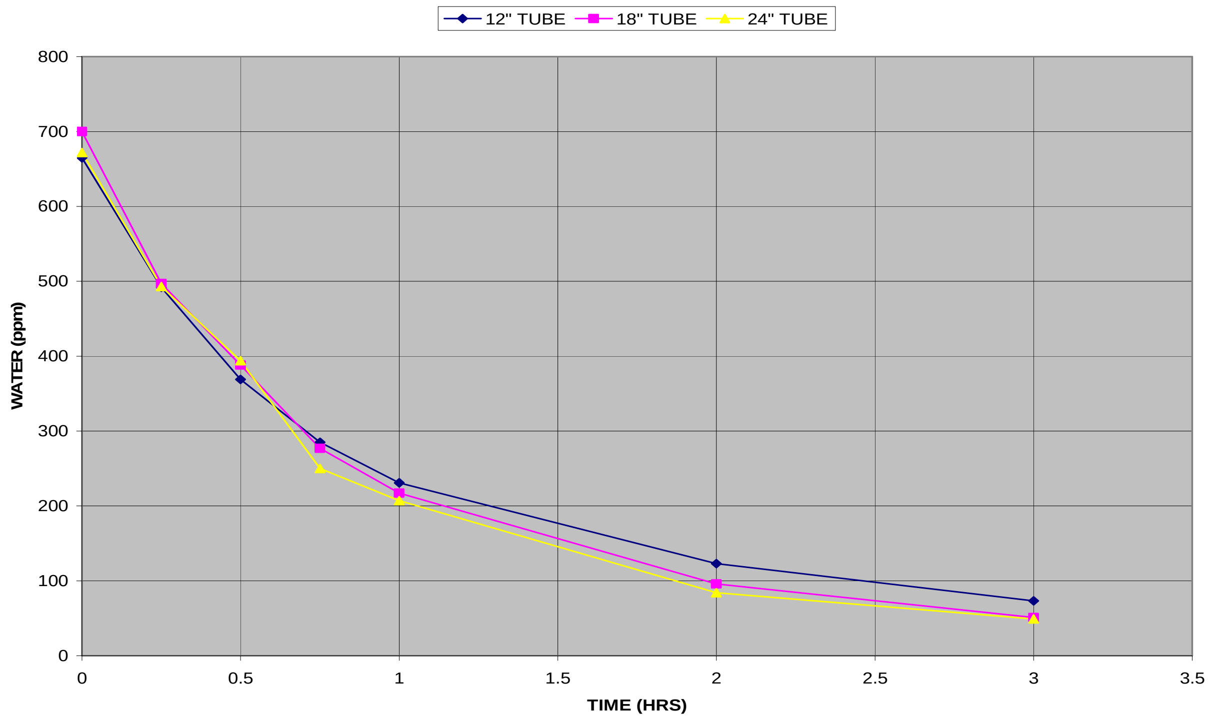

Table 1: Test results from run #1 using the two-drum purification process configuration

MLO #	Hrs	Comment	Sampling Point	PARTICLES NAS 1638	PARTICLES Gravimetric	H_2O PPM 100 MAX
05-0686	NA	New Fluid	Top	**6**	**0.37 Top&Mid Combined**	**99**
05-0687	NA	New Fluid	Middle	**6**		**91**
05-0688	NA	New Fluid	Bottom	**6**	NA	**91**
No MLO	NA	Contaminated with Particles only	Middle	**12**	NA	NA
No MLO	NA	Added water after particles	Middle	**NA**	NA	**613**
05-0689	0	Contaminated Fld no Purification	Top		**1.70**	**596**
05-0690	0	Contaminated Fld no Purification	Middle	**NA**	NA	**569**
05-0691	0	Contaminated Fld no Purification	Bottom		**1.59**	**543**
05-0692	24	Contaminated Fld no Purification	Top	**12**	NA	**574**
05-0693	24	Contaminated Fld no Purification	Middle	**12**	NA	**600**
05-0694	24	Contaminated Fld no Purification	Bottom	**12**	NA	**608**
05-0695	48	Contaminated Fld no Purification	Top	**11**	NA	**576**
05-0696	48	Contaminated Fld no Purification	Middle	**12**	NA	**590**
05-0697	48	Contaminated Fld no Purification	Bottom	**12**	NA	**597**
05-0698	72	Contaminated Fld no Purification	Top	**11**	**0.864**	**592**
05-0699	72	Contaminated Fld no Purification	Middle	**11**	NA	**589**
05-0700	72	Contaminated Fld no Purification	Bottom	**12**	**0.836**	**597**
05-0701	0	"1" Pass Pall Purifier to New Drum	Top	**6**	NA	**294**
05-0702	0	"1" Pass Pall Purifier to New Drum	Middle	**5**	NA	**290**
05-0703	0	"1" Pass Pall Purifier to New Drum	Bottom	**6**	NA	**288**
05-0704	0.25	Recycle New Drum with Pall	Top	**6**	NA	**336**
05-0705	0.25	Recycle New Drum with Pall	Middle	**5**	NA	**308**
05-0706	0.25	Recycle New Drum with Pall	Bottom	**6**	NA	**270**
05-0707	0.5	Recycle New Drum with Pall	Top	**6**	NA	**219**
05-0708	0.5	Recycle New Drum with Pall	Middle	**6**	NA	**239**
05-0709	0.5	Recycle New Drum with Pall	Bottom	**6**	NA	**215**
05-0710	0.75	Recycle New Drum with Pall	Top	**6**	NA	**175**
05-0711	0.75	Recycle New Drum with Pall	Middle	**5**	NA	**196**
05-0712	0.75	Recycle New Drum with Pall	Bottom	**5**	NA	**199**
05-0713	1	Recycle New Drum with Pall	Top	**5**	NA	**140**
05-0714	1	Recycle New Drum with Pall	Middle	**5**	NA	**152**
05-0715	1	Recycle New Drum with Pall	Bottom	**5**	NA	**156**
05-0716	2	Recycle New Drum with Pall	Top	**6**	NA	**74**
05-0717	2	Recycle New Drum with Pall	Middle	**6**	NA	**71**
05-0718	2	Recycle New Drum with Pall	Bottom	**4**	NA	**67**
05-0723	0	Contam Fld-No Purification-Residual	N/A	**12**	**1.38**	**520**

Table 2: Actual particle amounts over the 3-day settling period from run #1 using the two-drum purification process configuration

MLO #	Hrs	Sampling Point	PARTICLE COUNT 5-15uM 8000	15-25uM 1408	25-50uM 253	50-100uM 45	>100uM 8	NAS 1638 5
No MLO	0	Middle	532590	62375	15365	1205	45	**12**
05-0692	24	Top	519515	44195	4925	140	5	**12**
05-0693	24	Middle	594980	57070	8425	455	0	**12**
05-0694	24	Bottom	558470	56895	8620	300	5	**12**
05-0695	48	Top	481810	26210	1400	55	0	**11**
05-0696	48	Middle	551665	32325	2205	60	10	**12**
05-0697	48	Bottom	549305	36140	2560	40	0	**12**
05-0698	72	Top	443760	18155	650	55	0	**11**
05-0699	72	Middle	486405	23080	1265	55	5	**11**
05-0700	72	Bottom	512900	27350	1490	95	0	**12**

Table 3: Test results from run #2 using the two-drum purification process configuration

MLO #	Hrs	Comment	Sampling Point	PARTICLES NAS 1638	H_2O PPM 100 MAX
05-0849	NA	Uncontaminated Fluid	Middle	**5**	**51**
No MLO	NA	Contaminated with Particles only	Middle	**12**	NA
No MLO	NA	Added water after particles	Middle	**12**	**628**
05-0861	0	Contaminated Fld no Purification	Top	**12**	**625**
05-0862	0	Contaminated Fld no Purification	Middle	**12**	**628**
05-0863	0	Contaminated Fld no Purification	Bottom	**12**	**630**
05-0864	24	Contaminated Fld no Purification	Top	**12**	**534**
05-0865	24	Contaminated Fld no Purification	Middle	**12**	**478**
05-0866	24	Contaminated Fld no Purification	Bottom	**12**	**467**
05-0867	48	Contaminated Fld no Purification	Top	**12**	**558**
05-0868	48	Contaminated Fld no Purification	Middle	**12**	**565**
05-0869	48	Contaminated Fld no Purification	Bottom	**12**	**549**
05-0870	72	Contaminated Fld no Purification	Top	**12**	**564**
05-0871	72	Contaminated Fld no Purification	Middle	**12**	**585**
05-0872	72	Contaminated Fld no Purification	Bottom	**12**	**580**
05-0873	0	"1" Pass Pall Purifier to New Drum	Top	**6**	**300**
05-0874	0	"1" Pass Pall Purifier to New Drum	Middle	**7**	**308**
05-0875	0	"1" Pass Pall Purifier to New Drum	Bottom	**6**	**303**
05-0876	0.25	Recycle New Drum with Pall	Top	**7**	**251**
05-0877	0.25	Recycle New Drum with Pall	Middle	**7**	**278**
05-0878	0.25	Recycle New Drum with Pall	Bottom	**6**	**278**
05-0879	0.5	Recycle New Drum with Pall	Top	**6**	**186**
05-0880	0.5	Recycle New Drum with Pall	Middle	**6**	**211**
05-0881	0.5	Recycle New Drum with Pall	Bottom	**6**	**208**
05-0882	0.75	Recycle New Drum with Pall	Top	**7**	**171**
05-0883	0.75	Recycle New Drum with Pall	Middle	**7**	**170**
05-0884	0.75	Recycle New Drum with Pall	Bottom	**6**	**164**
05-0885	1	Recycle New Drum with Pall	Top	**7**	**131**
05-0886	1	Recycle New Drum with Pall	Middle	**6**	**142**
05-0887	1	Recycle New Drum with Pall	Bottom	**7**	**137**
05-0888	2	Recycle New Drum with Pall	Top	**7**	**92**
05-0889	2	Recycle New Drum with Pall	Middle	**7**	**96**
05-0890	2	Recycle New Drum with Pall	Bottom	**6**	**70**
05-0908	3	Recycle New Drum with Pall	Top	**5**	**71**
05-0909	3	Recycle New Drum with Pall	Middle	**4**	**47**
05-0910	3	Recycle New Drum with Pall	Bottom	**6**	**60**
05-0911	4	Recycle New Drum with Pall	Top	**5**	**54**
05-0912	4	Recycle New Drum with Pall	Middle	**4**	**47**
05-0913	4	Recycle New Drum with Pall	Bottom	**5**	**48**

Table 4: Actual particle amounts over the 3-day settling period from run #2 using the two-drum purification process configuration

			PARTICLE COUNT					
		Sampling	5-15uM	15-25uM	25-50uM	50-100uM	>100uM	NAS 1638
MLO #	Hrs	Point	8000	1408	253	45	8	5
05-0861	0	Top	615960	87115	27255	3045	50	**12**
05-0862	0	Middle	618455	80855	25290	2665	55	**12**
05-0863	0	Bottom	689215	94500	26100	2430	40	**12**
05-0864	24	Top	740175	70440	7925	80	5	**12**
05-0865	24	Middle	555895	65775	12805	190	5	**12**
05-0866	24	Bottom	658960	87490	17280	490	0	**12**
05-0867	48	Top	681960	21280	875	70	5	**12**
05-0868	48	Middle	731315	58530	3265	125	10	**12**
05-0869	48	Bottom	612025	33770	1505	35	0	**12**
05-0870	72	Top	655590	9895	580	55	5	**12**
05-0871	72	Middle	711335	39600	1805	60	5	**12**
05-0872	72	Bottom	739190	46645	2265	75	0	**12**

Table 5: Test results from the single-drum purification process configuration using the 12”-long discharge tube

		Sampling	PARTICLES	H_2O ppm
MLO #	Hrs	Point	NAS 1638	100 MAX
05-0784	0	Middle	**12**	**665**
05-0785	0.25	Top	**11**	**506**
05-0786	0.25	Middle	**11**	**484**
05-0787	0.25	Bottom	**11**	**487**
05-0788	0.5	Top	**10**	**368**
05-0789	0.5	Middle	**10**	**367**
05-0790	0.5	Bottom	**10**	**373**
05-0791	0.75	Top	**8**	**283**
05-0792	0.75	Middle	**9**	**284**
05-0793	0.75	Bottom	**9**	**289**
05-0794	1	Top	**7**	**227**
05-0795	1	Middle	**7**	**233**
05-0796	1	Bottom	**8**	**233**
05-0797	2	Top	**5**	**124**
05-0798	2	Middle	**5**	**112**
05-0799	2	Bottom	**5**	**134**
05-0839	3	Top	**6***	**64**
05-0840	3	Middle	**7***	**77**
05-0841	3	Bottom	**6***	**78**
			*** Ran Water Test First**	

Table 6: Test results from the single-drum purification process configuration using the 18”-long discharge tube

MLO #	Hrs	Sampling Point	PARTICLES NAS 1638	H_2O ppm 100 MAX
05-0800	0	Middle	**12**	**700**
05-0801	0.25	Top	**12**	**515**
05-0802	0.25	Middle	**12**	**500**
05-0803	0.25	Bottom	**12**	**476**
05-0804	0.5	Top	**10**	**376**
05-0805	0.5	Middle	**11**	**397**
05-0806	0.5	Bottom	**11**	**391**
05-0807	0.75	Top	**9**	**277**
05-0808	0.75	Middle	**9**	**275**
05-0809	0.75	Bottom	**9**	**280**
05-0810	1	Top	**7**	**200**
05-0811	1	Middle	**8**	**222**
05-0812	1	Bottom	**8**	**229**
05-0813	2	Top	**5**	**97**
05-0814	2	Middle	**4**	**94**
05-0815	2	Bottom	**4**	**96**
05-0845	3	Top	**4**	**53**
05-0846	3	Middle	**4**	**52**
05-0847	3	Bottom	**4**	**49**

Table 7: Test results from the single-drum purification process configuration using the 24”-long discharge tube

MLO #	Hrs	Sampling Point	PARTICLES NAS 1638	H_2O ppm 100 MAX
05-0816	0	Middle	**12**	**672**
05-0817	0.25	Top	**11**	**446**
05-0818	0.25	Middle	**12**	**500**
05-0819	0.25	Bottom	**12**	**533**
05-0820	0.5	Top	**10**	**378**
05-0821	0.5	Middle	**10**	**398**
05-0822	0.5	Bottom	**11**	**407**
05-0823	0.75	Top	**8**	**218**
05-0824	0.75	Middle	**9**	**268**
05-0825	0.75	Bottom	**9**	**264**
05-0826	1	Top	**5**	**184**
05-0827	1	Middle	**7**	**220**
05-0828	1	Bottom	**8**	**218**
05-0829	2	Top	**4**	**78**
05-0830	2	Middle	**4**	**84**
05-0831	2	Bottom	**5**	**89**
05-0848	3	Top	**5**	**50**
05-0849	3	Middle	**5**	**51**
05-0850	3	Bottom	**4**	**46**